Development of Nonlinear Harmonic Sensors for Detection of Mechanical Damage

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Presented by

Southwest Research Institute

(Co-funding by Tuboscope Varco Inc.)

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Project Objectives

- Develop optimum sensor design
- Design an in-line NLH system
- Fabricate and install NLH capability on the TPS pilot pig
- Validate performance with extensive testing in laboratory and pull rig

Requirements of In-Line Mechanical Damage Sensing

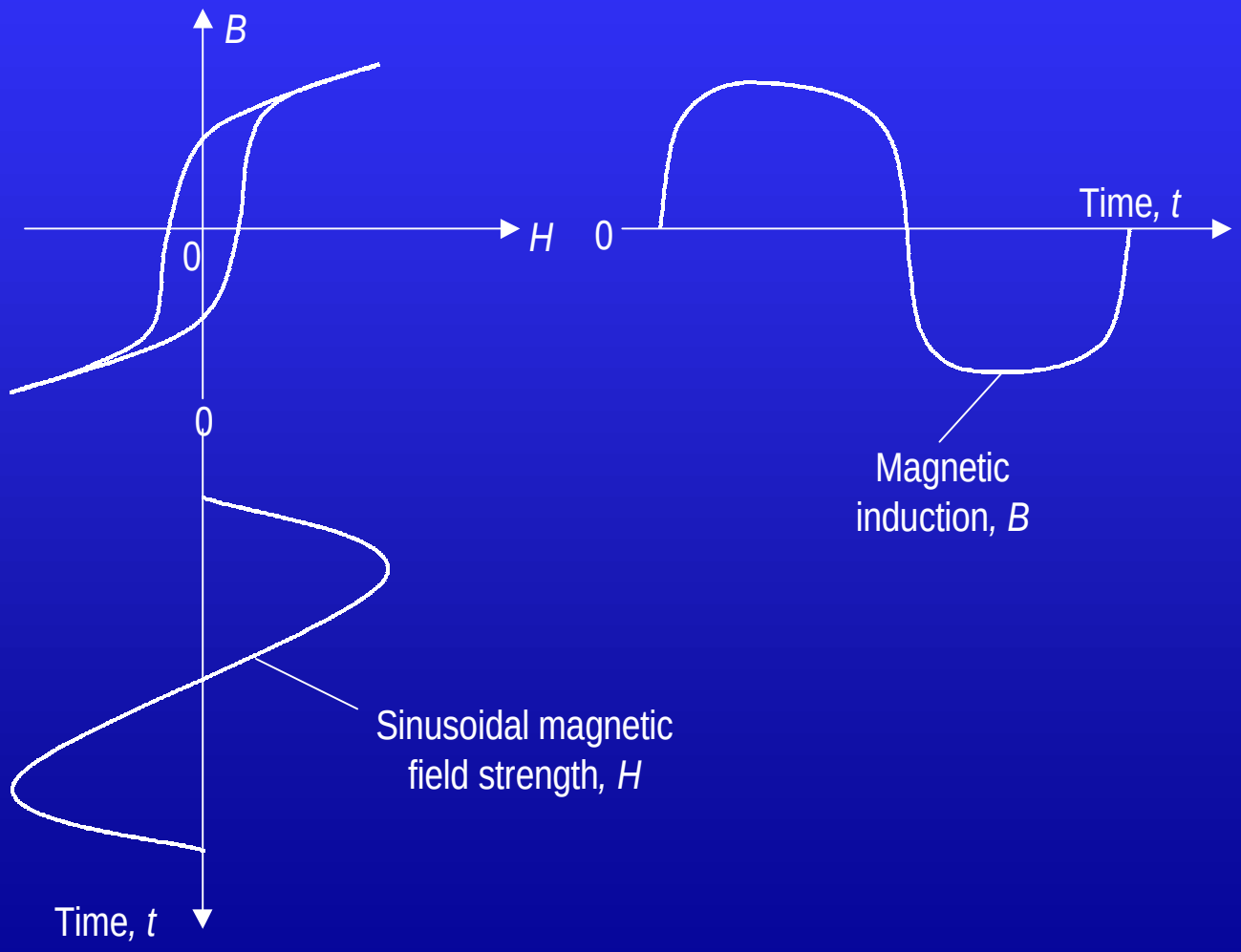
- Tolerate vibration in the sensor
- Low power consumption
- Sensors immune to pressure and contamination of product
- Operate at reasonable velocity to minimize inspection times

Nonlinear Harmonics Sensors for Detection of Mechanical Damage

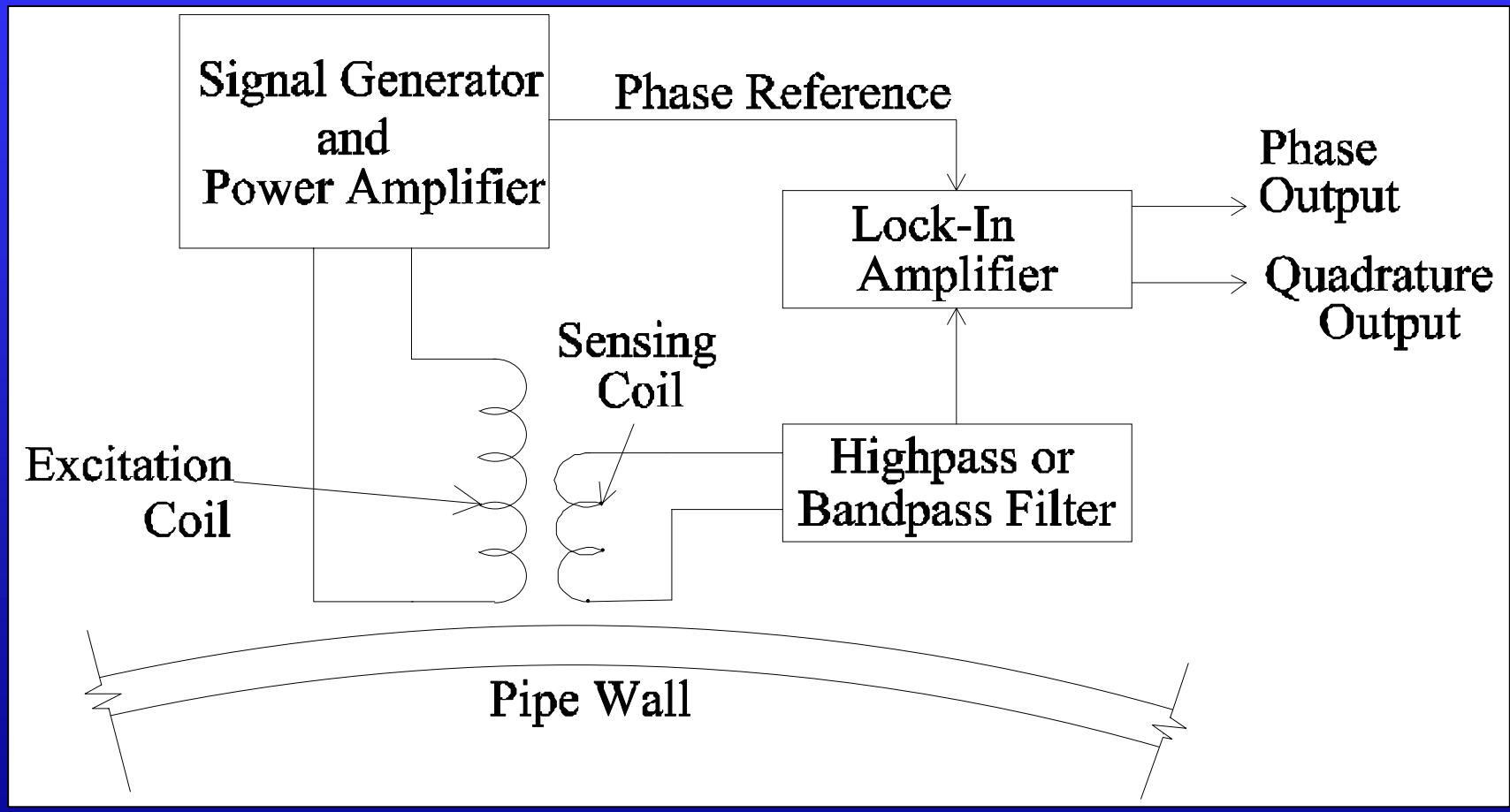
Principles of NLH Method

- Application of AC magnetic field causes production of odd-numbered harmonic frequencies in magnetic induction because magnetization curve is nonlinear
- Amplitude and phase of third-harmonic frequency is measured
- Stress and plastic deformation change magnetic properties (magnetoelastic effect) and thus third harmonic

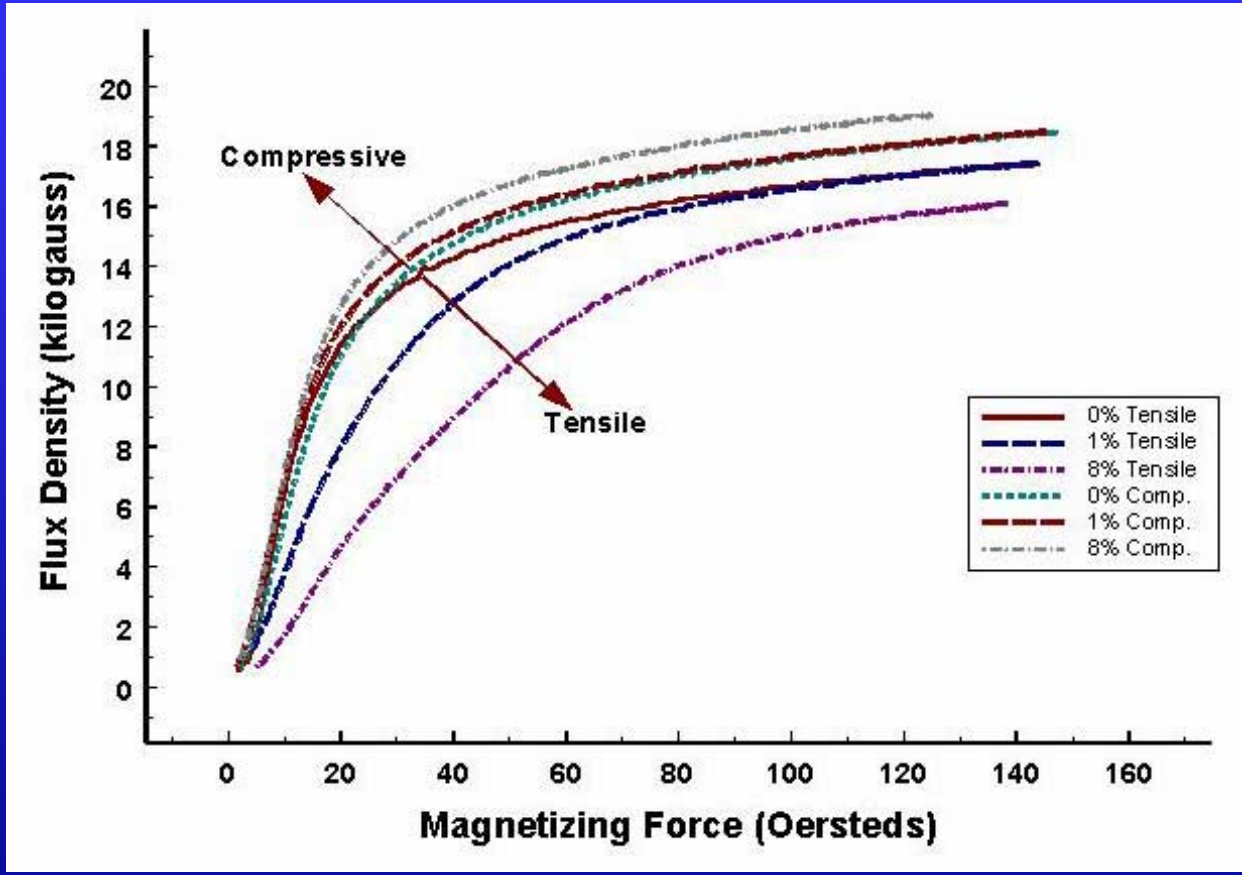
NLH Generation



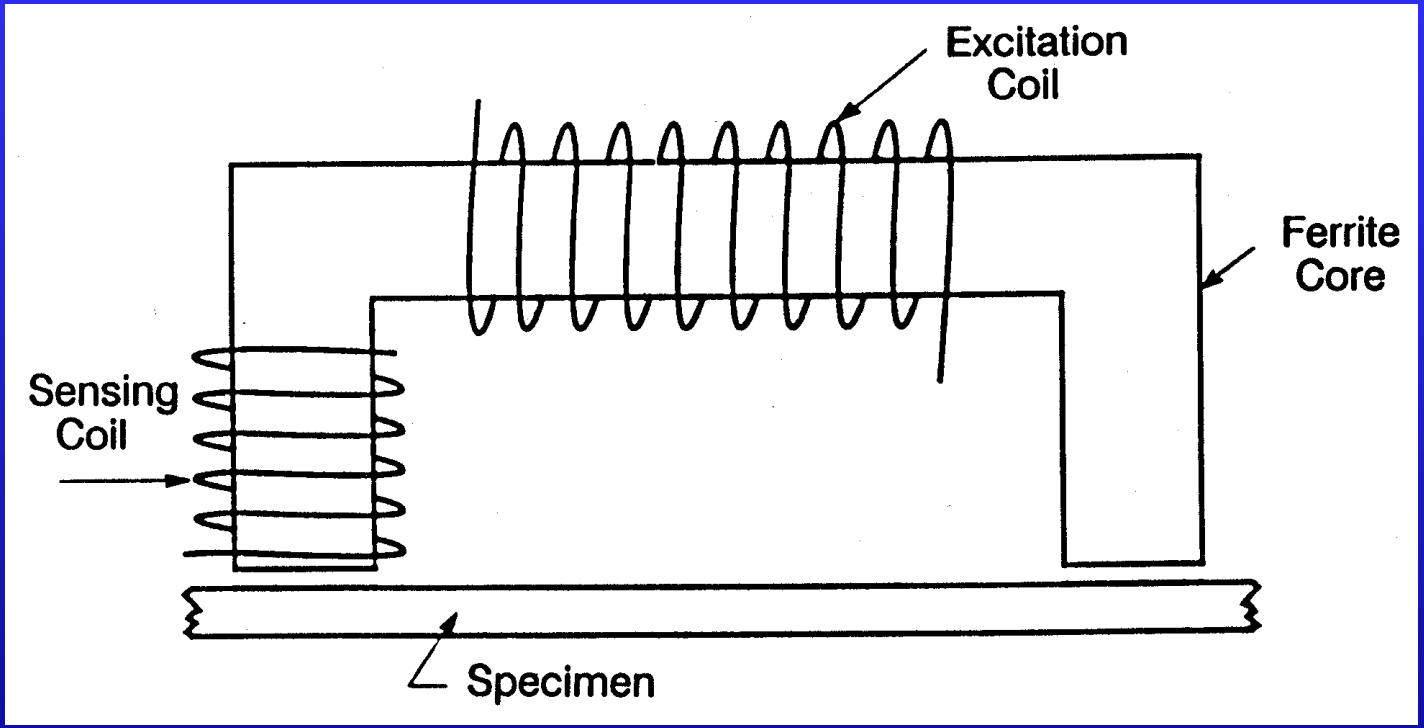
NLH Block Diagram



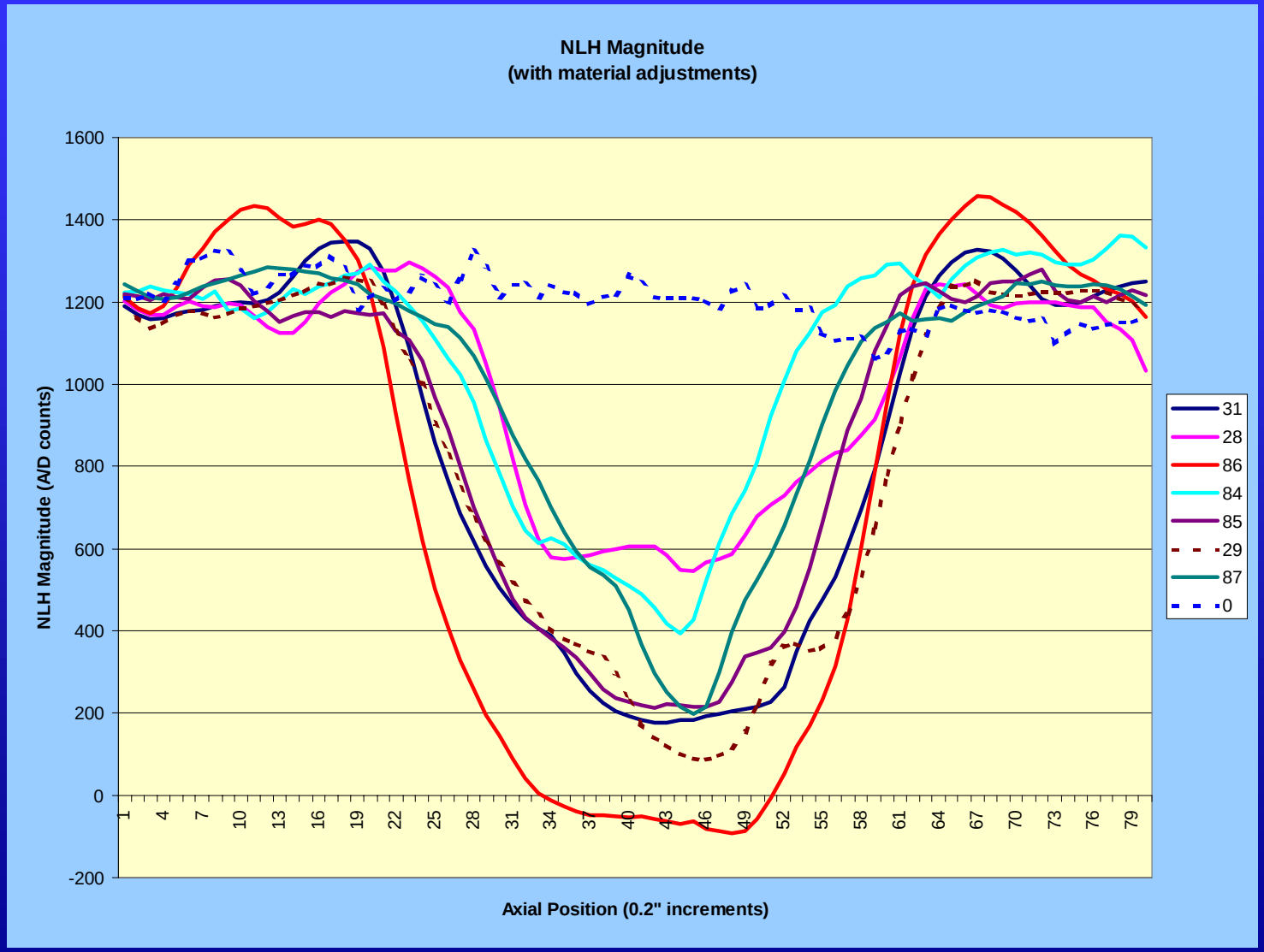
Effects of Plastic Deformation on Magnetization Curves



NLH Probe Configuration

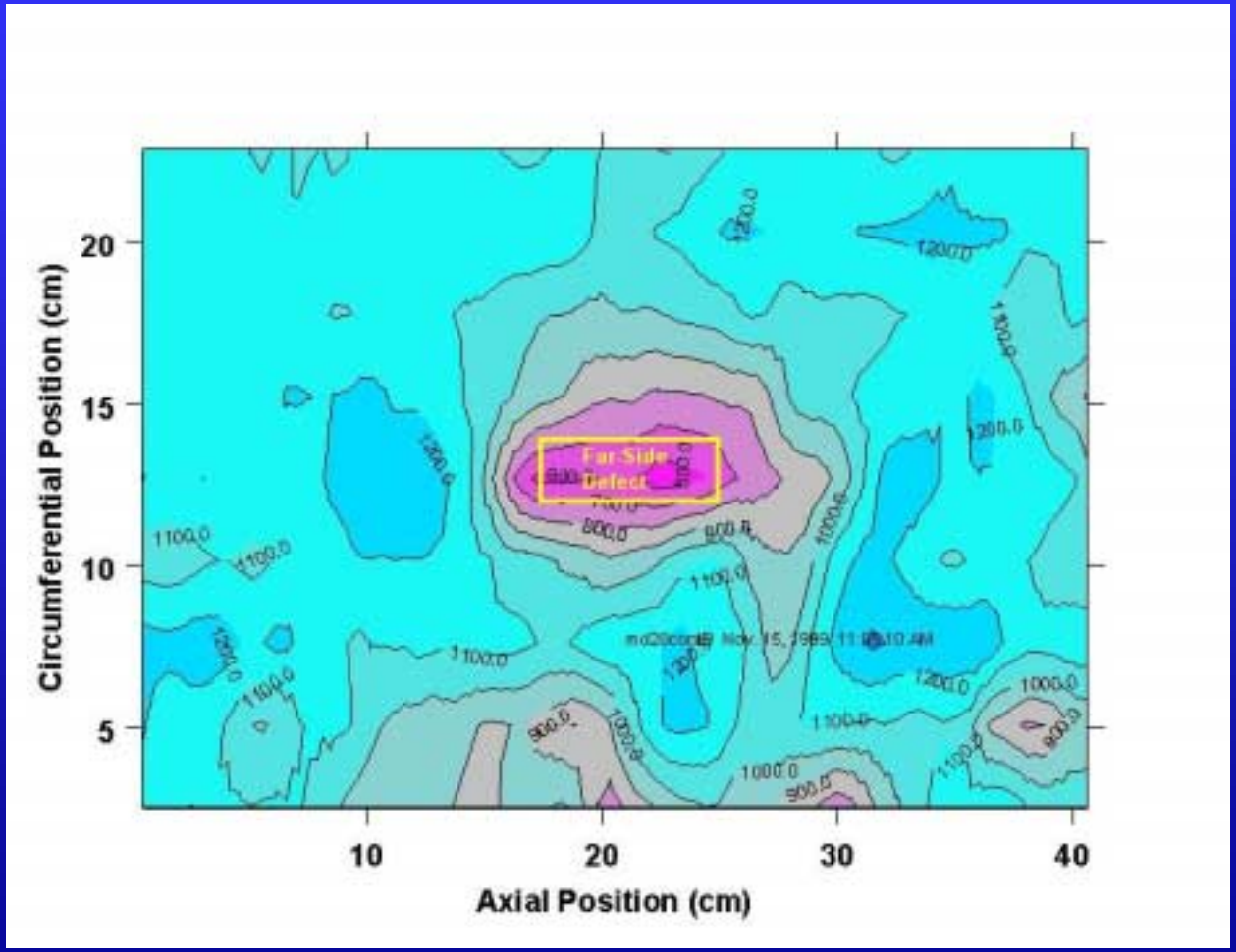


NLH Magnitude - Eight Defects



Gouge Without Dent

NLH Response to Gouge with No I.D. Deformation

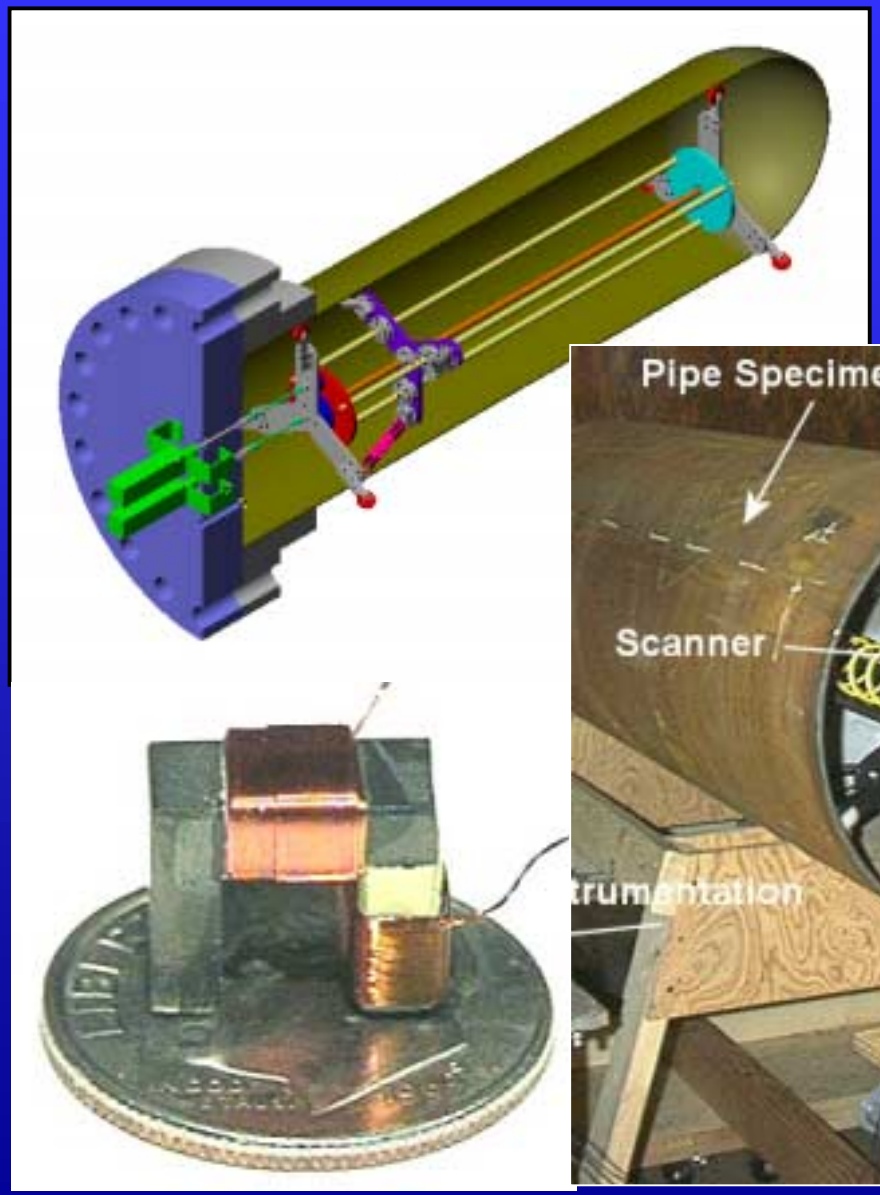


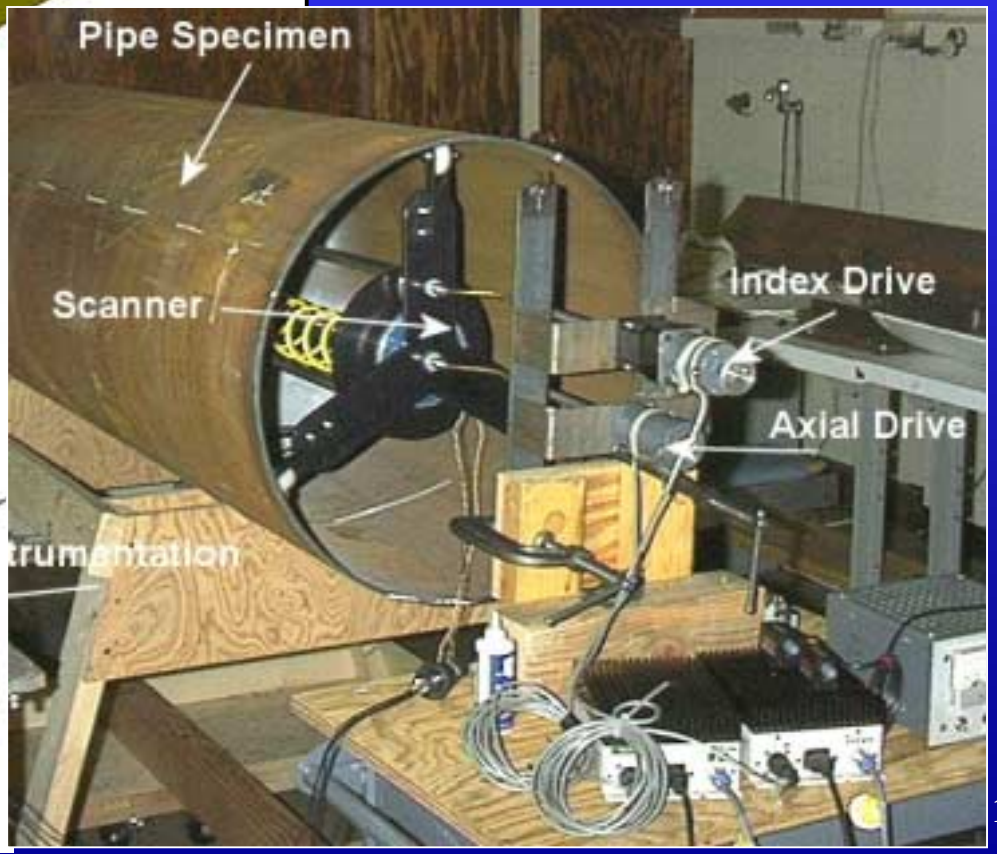
Laboratory Experiments

- Measure NLH response to dents/gouges of various severities
  - No pressure
  - Pressure
- Data taken as probe is scanned in raster pattern by mechanized scanner

NLH Testing Set-Up

NLH Scanner Deployment



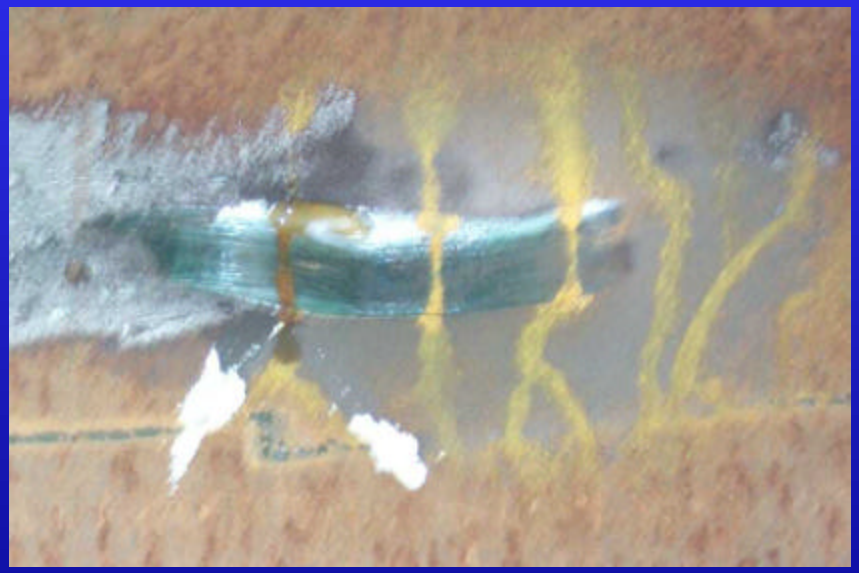


Defect Set

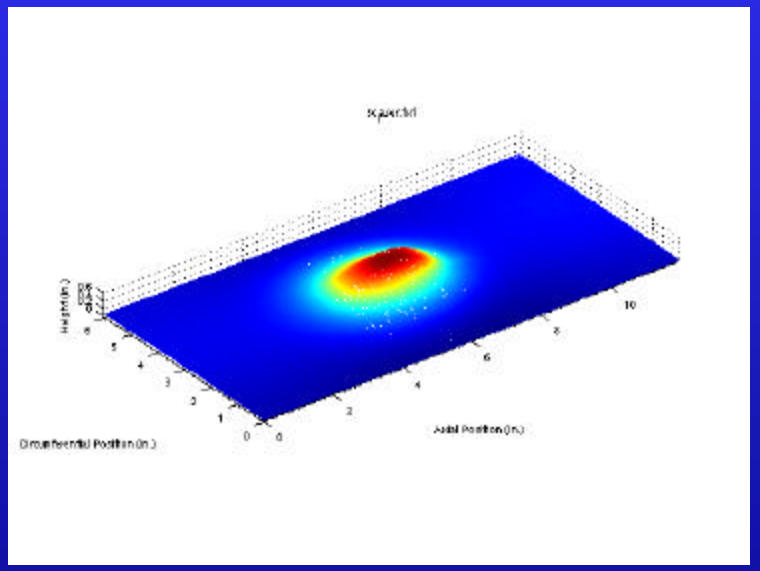
- 18 Defects
- Dent depths from 0.12 to 0.96 inch before re-rounding from internal pressure
- Gouge Lengths from 0 to 6 inch
- Width of tool: 0.33, 0.5, 0.75 inch

Typical Defect (5C)

- Photo (O.D.)

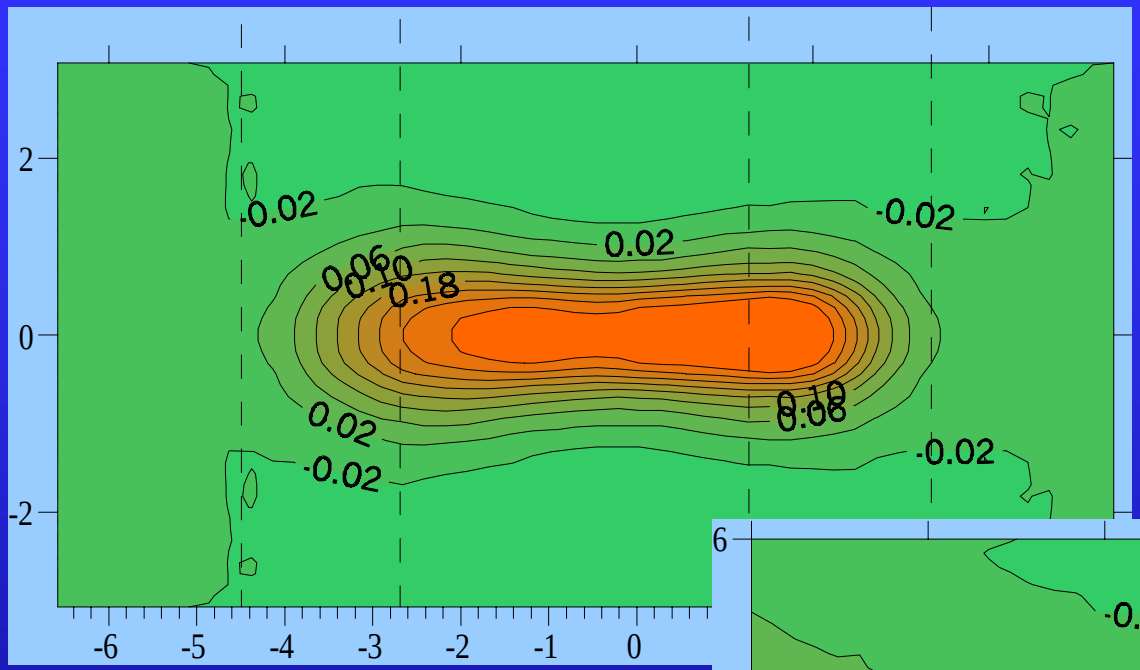


- Laser Profile (I.D.)

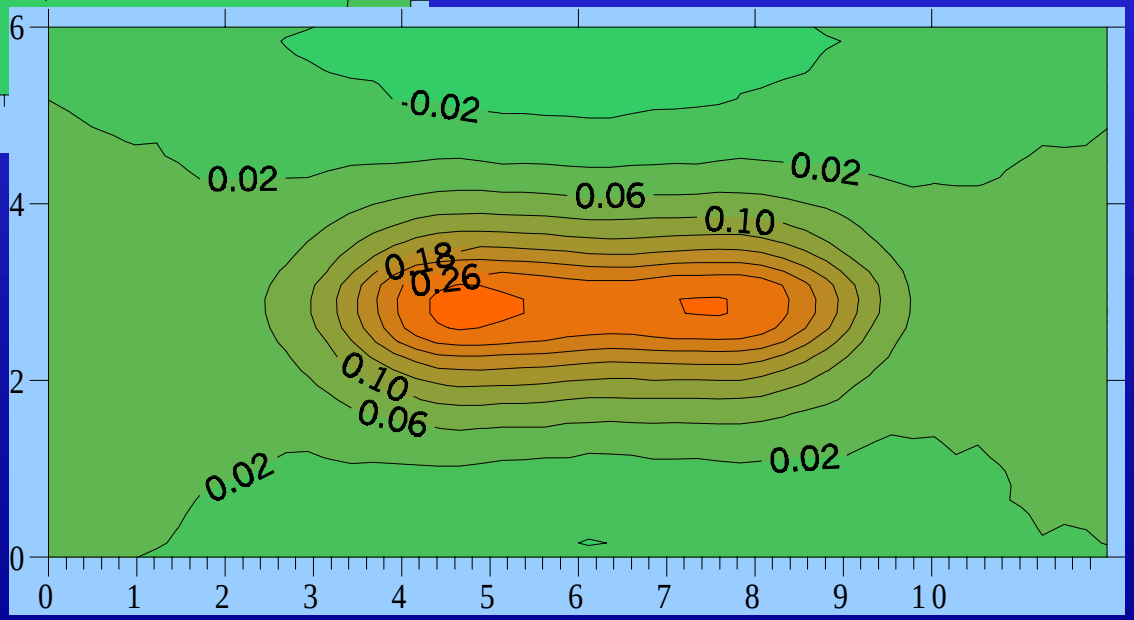


Radial Deformation Defect 3c

FEA Prediction

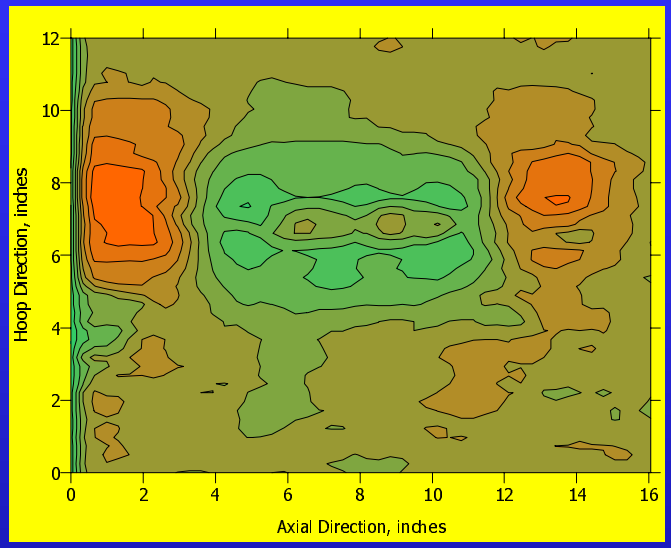


Laser Scan

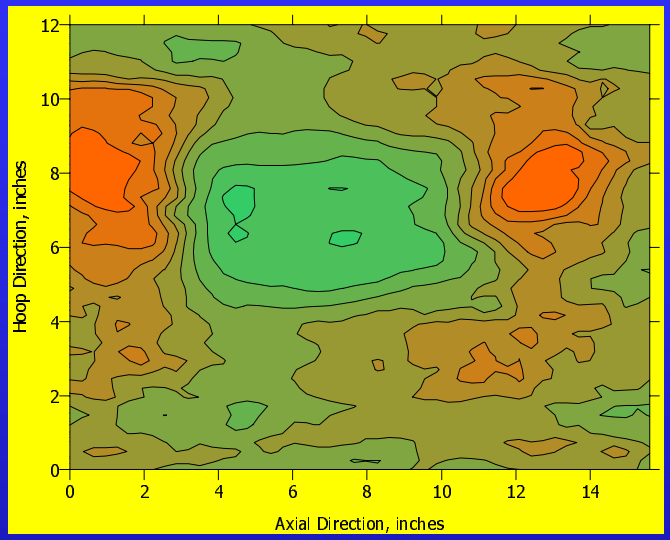


2.5% deep (before re-round)
6 inches axial travel
Square indenter

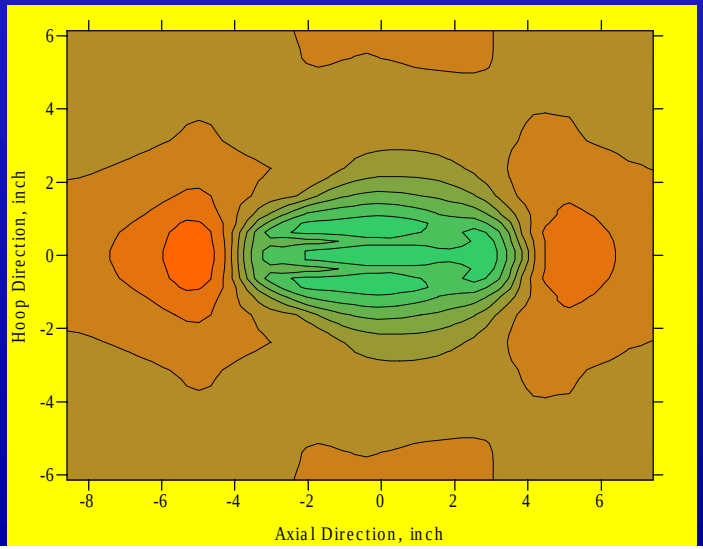
Comparison of Axial NLH Signals and Axial Stress: Defect 3c, 800 psi 2.5% Dent, Square Tool, 6-inch Gouge



NLH Signals (uncorrected)

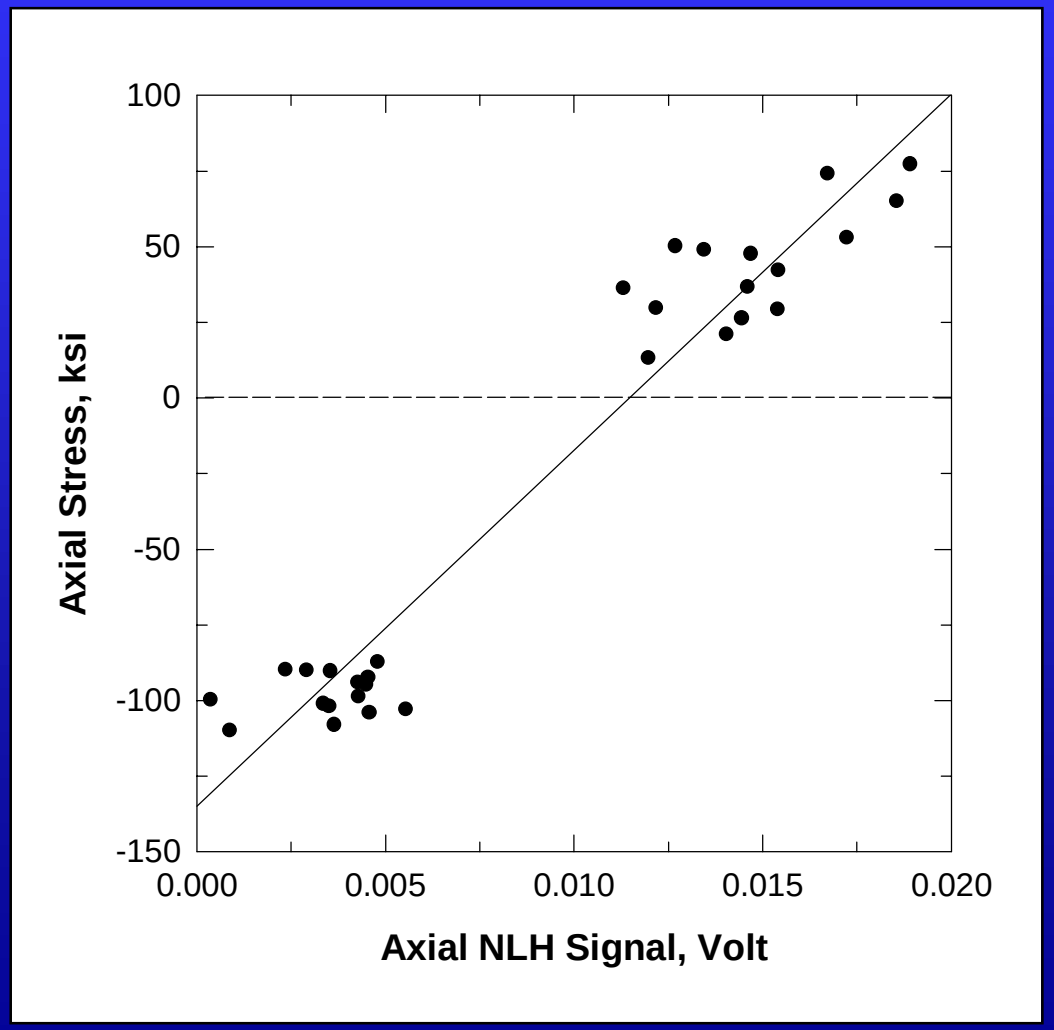


NLH Signals (Liftoff corrected)

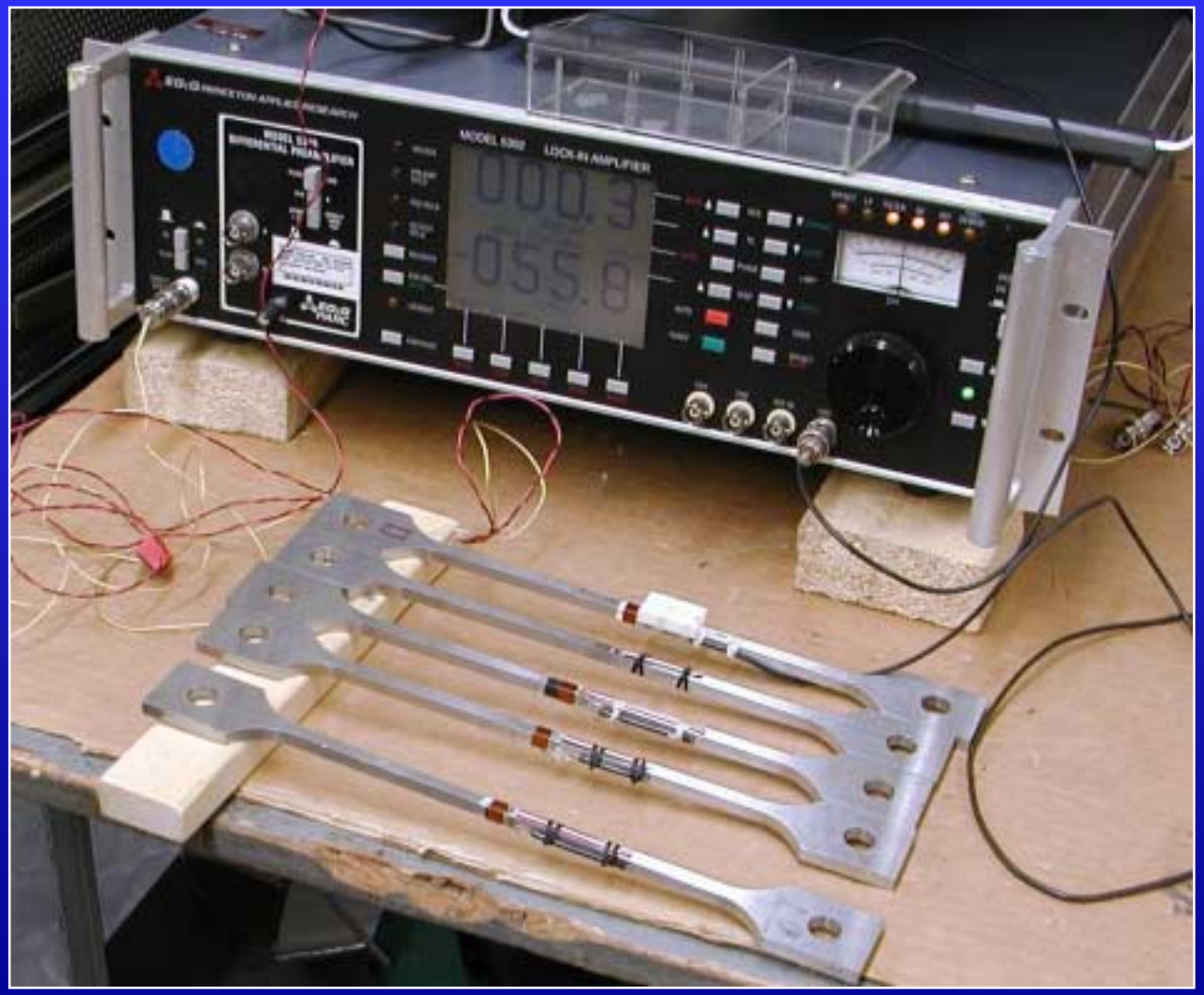


FEA results

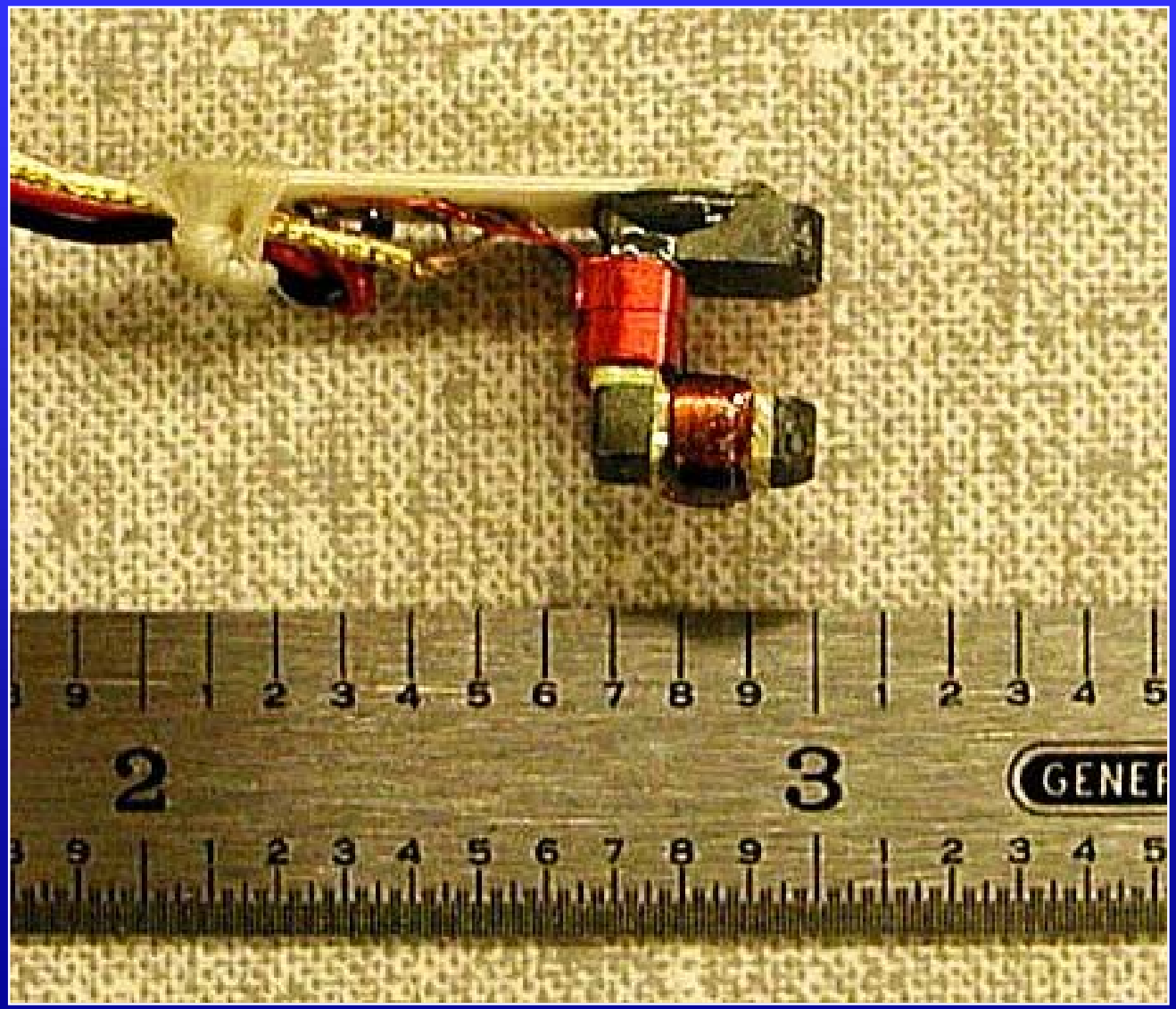
Correlation between NLH Signal and FEA Predicted Stress



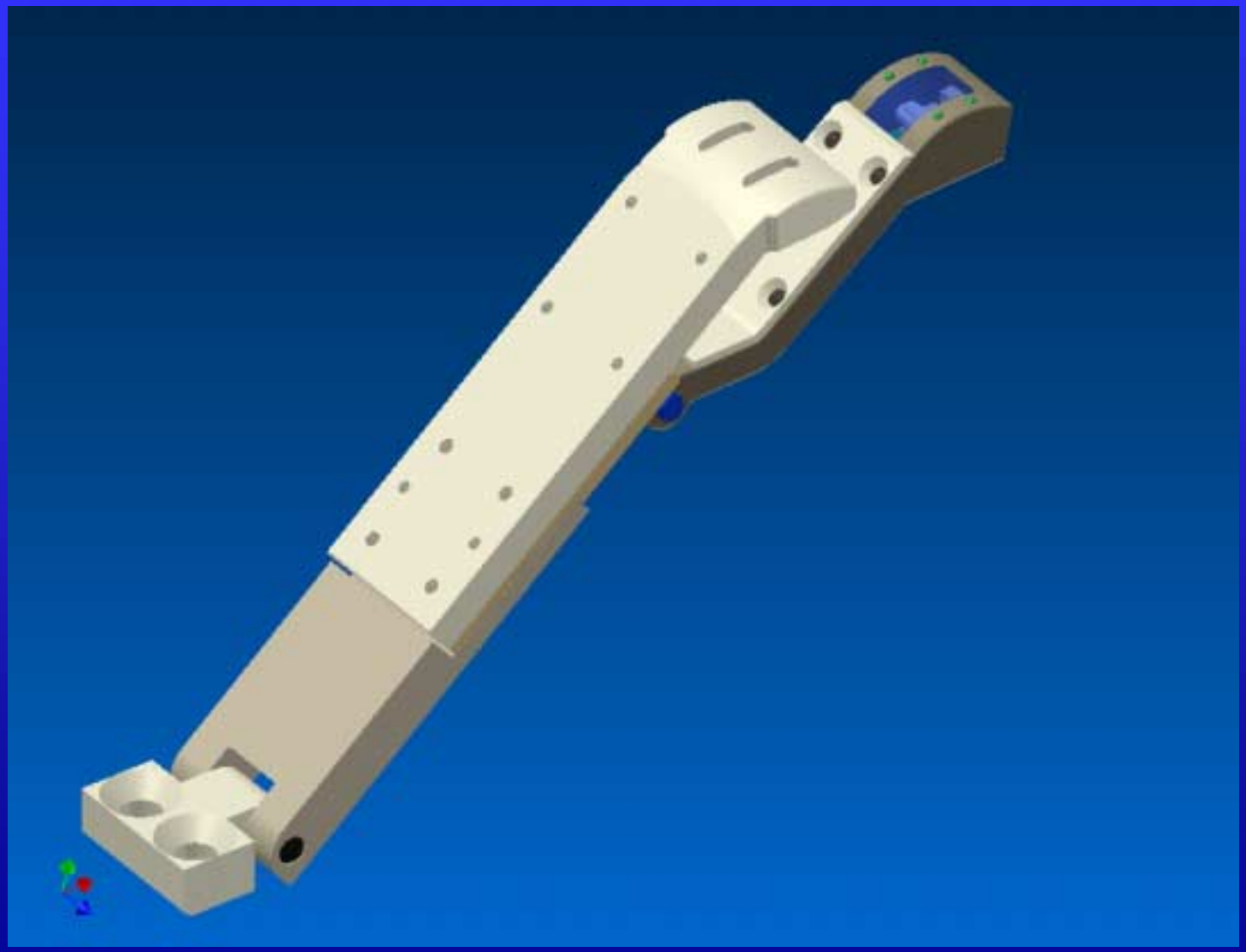
Coupons for Residual Field Tests



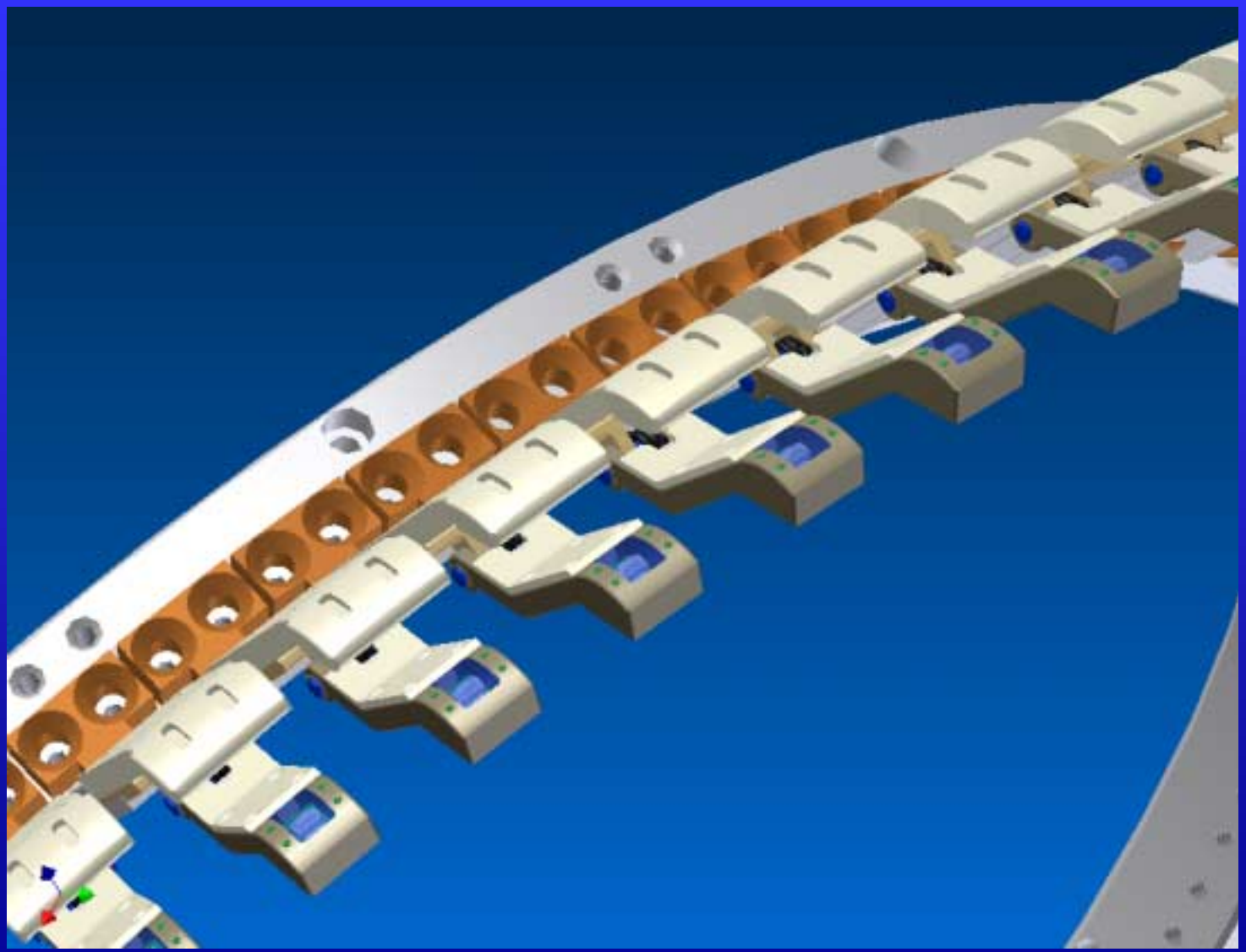
Varco Prototype Probe



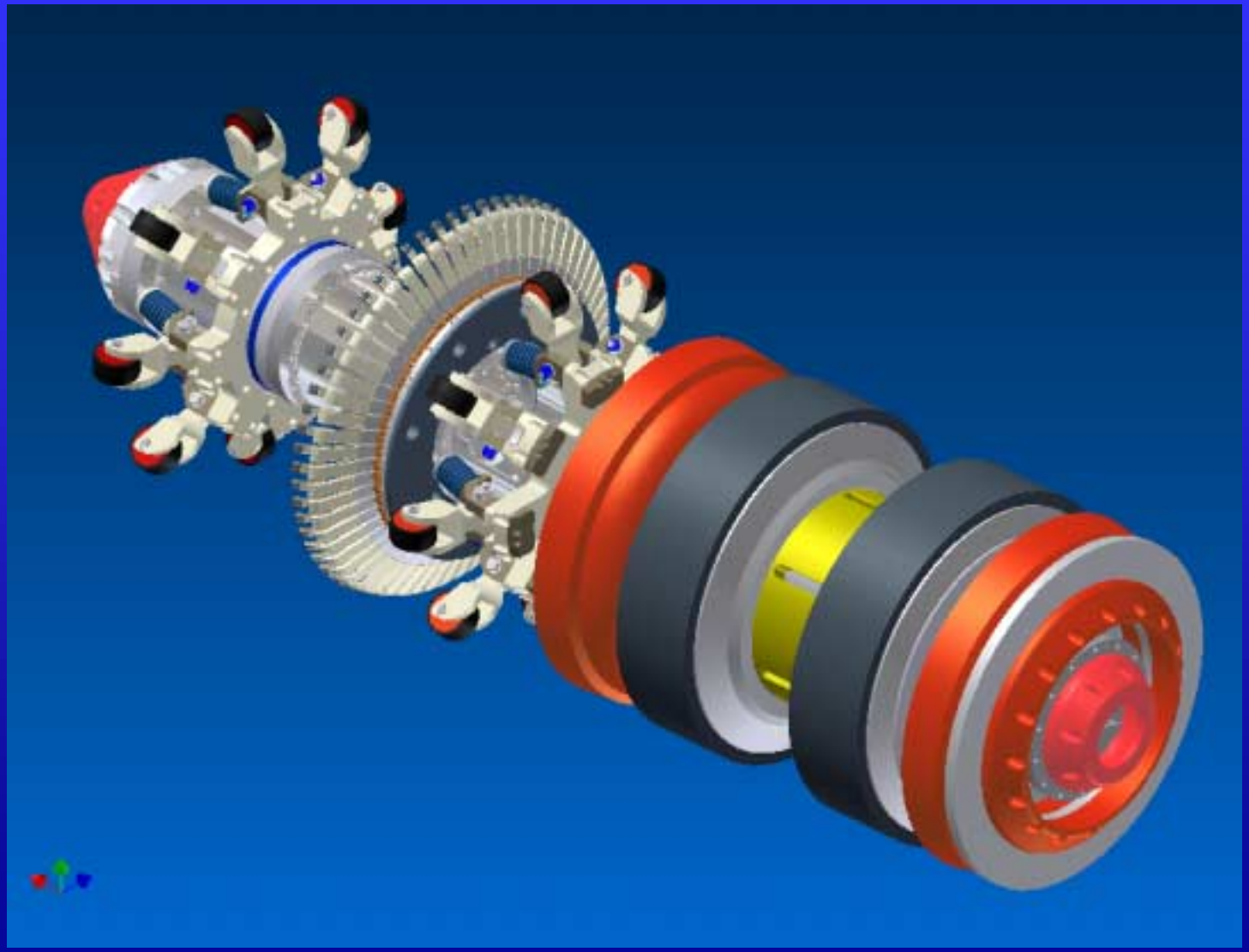
NLH Sensor Suspension



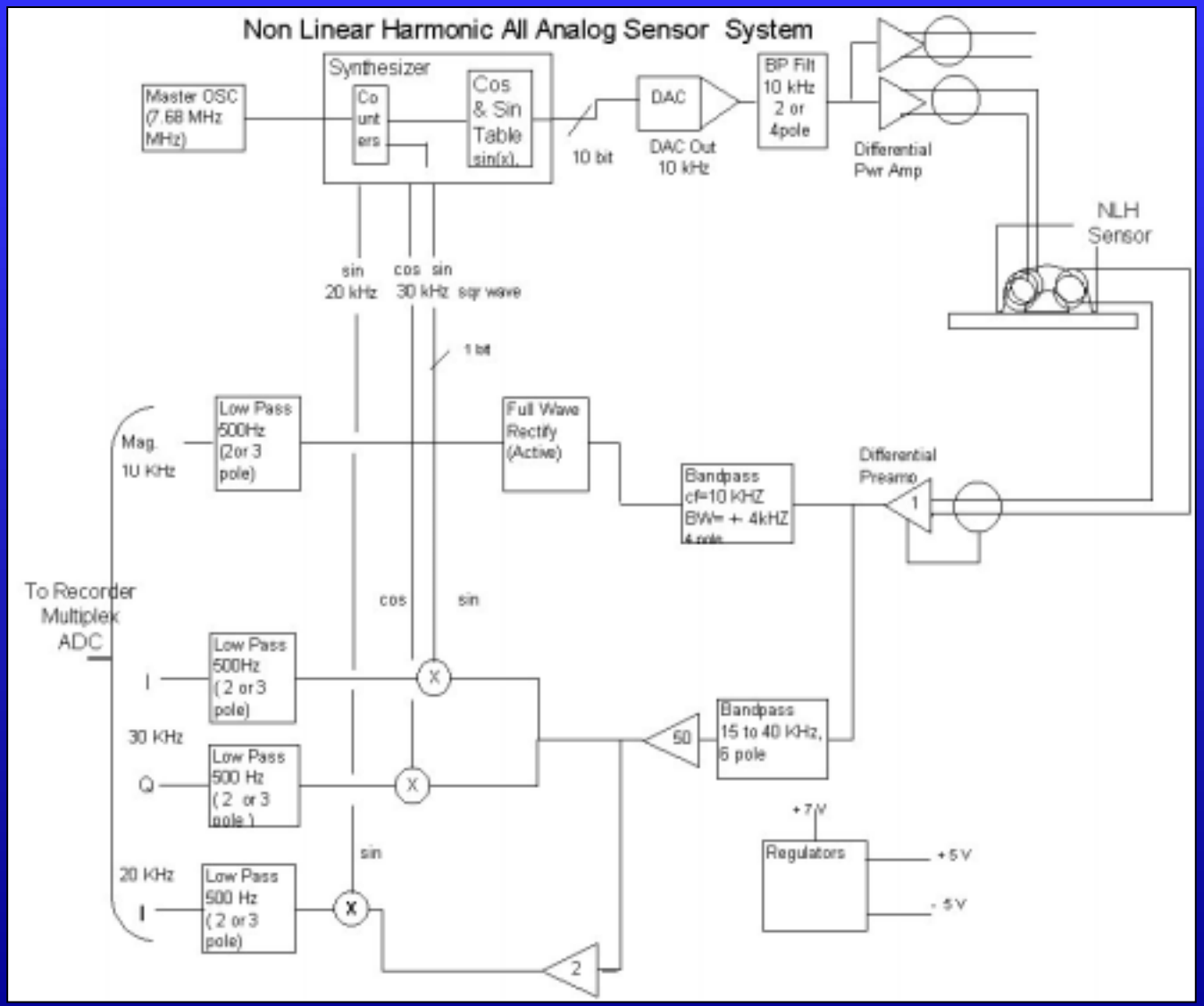
Section of Sensor Ring



NLH Sensors in Place on Pig



Single-Channel Electronics



Conclusions to-date from DOT Project

- **NLH can detect dents and gouges in pipeline steel.**
- **NLH signal strengths are related to the stresses on the pipe inner surface, FEA provides the link between these two parameters.**
- **Work is progressing towards identifying an NDE-based defect severity criterion using FEA results to supplement NDE measurements.**

Conclusions to Date from DOE Project

- Sensor design has been optimized and transferred to Tuboscope for fabrication
- Design concept of interface electronics has been completed
- Sensor suspension design concept is complete